REPORT DOCUMENTATION PAGE	Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
24-02-2011	Final Report	1-Oct-2009 - 31-Dec-2010

4. TITLE AND SUBTITLE
JET FUEL PRODUCTION FROM TAG AND FAME

5a. CONTRACT NUMBER
W911NF-09-1-0578

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
9620BB

6. AUTHORS
Benjamin G. Oster

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
University of North Dakota
264 Centennial Drive-Twamley Hall

Grand Forks, ND 58202 -

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
57241-CH-DRP.1

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
The Energy & Environmental Research Center (EERC) and its partners have developed thermocatalytic technologies to produce a 100% renewable fuel from crop oil-derived triglyceride (TAG) feedstock that meets the critical military specification requirements of JP-8 as demonstrated by analysis conducted at the Air Force Research Laboratory (AFRL). The EERC process has demonstrated the ability to convert many types of crop oil TAG into hydrocarbon products. This project utilized the EERC process to convert algae oil TAG into JP-8 fuel components.

15. SUBJECT TERMS
algae, JP-8, renewable fuel, jet fuel

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UU	UU	UU	UU		Benjamin Oster
					19b. TELEPHONE NUMBER
					701-777-5203

Report Title

JET FUEL PRODUCTION FROM TAG AND FAME

ABSTRACT

The Energy & Environmental Research Center (EERC) and its partners have developed thermocatalytic technologies to produce a 100% renewable fuel from crop oil-derived triglyceride (TAG) feedstock that meets the critical military specification requirements of JP-8 as demonstrated by analysis conducted at the Air Force Research Laboratory (AFRL). The EERC process has demonstrated the ability to convert many types of crop oil TAG into hydrocarbon products. This project utilized the EERC process to convert algae oil TAG into JP-8 fuel components.

The fuel production process included hydrodeoxygenation of the algae feedstock to produce hydrocarbons, isomerization of the hydrocarbons, distillation of the isomerized hydrocarbons, and aromatics blending.

The EERC produced a 230-mL sample of finished JP-8 jet fuel and shipped it to AFRL for analysis. Initial EERC analysis indicated that the sample met JP-8 freeze point and flash point specifications.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

(d) Manuscripts

Number of Manuscripts: 0.00

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):	0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:	0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

JET FUEL PRODUCTION FROM TAG AND FAME

INTRODUCTION

Historically, the U.S. Army has relied on petroleum-based JP-8 fuel to power its vehicles and aircraft. In order to increase the surety of the Army's fuel supply, researchers are investigating JP-8 production pathways that convert alternative, domestic feedstocks into specification-compliant fuel. Algae is one promising feedstock because of its potential to produce very high yields of oil/acre/year and its ability to grow on nonfarmable land.

OBJECTIVE

The objective of this research was to demonstrate that algae-derived triglyceride oil can be processed into JP-8 fuel. Crude algae oil was shipped to the Energy & Environmental Research Center (EERC) by the Army Research Office. The crude algae oil was green and viscous, as shown in Figure 1.

EXPERIMENTAL

Due to the crude nature of the algae oil as-received, it could not be processed without further purification. The algae could not be pumped, even when heated, and contained solid plant matter. As such, the algae was shipped to POS Pilot Plant Corporation where it was purified via de-gumming and bleaching.

After receiving the purified algae oil from POS, the EERC began to process the algae oil into jet fuel range hydrocarbons. The crude algae oil was first pumped into a hydrodeoxygenation (HDO) reactor where the triglyceride oil was converted to hydrocarbons via three chemical reactions: 1) decarboxylation, 2) decarbonylation, and 3) reduction. Decarboxylation removes carbon and oxygen atoms from the parent triglyceride by the formation of carbon dioxide. Decarbonylation removes carbon and oxygen from the parent triglyceride by the formation of carbon monoxide. Reduction removes oxygen from the parent triglyceride by the formation of water. Reactions that remove carbon and oxygen result in hydrocarbons that contain one carbon less than the parent triglyceride. The reduction reaction, which only removes oxygen, results in hydrocarbons that contain an equal number of carbon atoms as the parent triglyceride. Because all three reactions occur simultaneously, the HDO product contains both odd and even numbered hydrocarbons.

The HDO reactor operated at elevated temperature and pressure and contained a fixed bed of commercial hydrotreating catalyst. A picture of the HDO reactor is shown in Figure 2. The HDO reactor products were hydrocarbons, carbon dioxide, carbon monoxide, and water. The hydrocarbon product was separated from the water layer for further processing. Specifically, a separation funnel was used to separate the hydrocarbon layer from the water layer. Typically, the HDO product contains 90mass% hydrocarbon and 10mass% water.

The hydrocarbon product from the HDO step contained predominantly normal paraffins. In order to improve cold-flow properties, the HDO product was pumped into an isomerization reactor. In this reactor, the normal hydrocarbons were branched to form isoparaffins, which have improved cold flow properties. Cracking reactions also occur in the isomerization reactor. These reactions convert longer chain hydrocarbons into shorter chain hydrocarbons. The isomerization reactor operated at elevated temperature and pressure and contained a fixed bed of isomerization catalyst. The product from the isomerization reactor contained a broad range of hydrocarbons and an increased concentration of isoparaffins.

The isoparaffin mixture was distilled in a batch distillation apparatus to separate jet range hydrocarbons from the product mixture. Finally, petroleum-derived aromatics were added to the jet range hydrocarbons in order to meet the JP-8 density specification. The blended JP-8 sample contained 140 g of algae-derived hydrocarbons and 42 g of petroleum aromatics.

RESULTS

A gas chromatography–mass spectrometry (GC–MS) instrument was used to analyze the algae-derived jet fuel, and as Figure 3 shows, the hydrocarbon composition was similar to that of JP-8 (JP-8 contains hydrocarbons ranging from C8 to C16). The blended JP-8 sample, shown in Figure 4, was analyzed at the EERC for freeze and flash points. The sample's freeze point was −63°C and its flash point was 44°C. JP-8 specifications dictate a freeze point below −47ºC and a flash point above 38°C. The finished fuel sample was shipped to the Air Force Research Laboratory (AFRL) for further analysis.

CONCLUSIONS

Algae oil was successfully converted to jet-range hydrocarbons. The process consisted of three steps: 1) hydrodeoxygenation 2) isomerization and 3) distillation. Aromatics were added and the algae-derived JP-8 sample was shipped to AFRL for further analysis. In the future, algae oil could provide an alternative to petroleum for fueling military vehicles and aircraft.

Technology Transfer

JET FUEL PRODUCTION FROM TAG AND FAME

Final Report

(*for the period of October 1, 2009, through December 31, 2010*)

Prepared for:

Robert Mantz

Electrochemistry and Advanced Energy Conversion Program
U.S. Army Research Office
PO Box 12211
Research Triangle Park, NC 27709-2211

Grant No.: W911NF-09-1-0578

Prepared by:

Benjamin G. Oster

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

2010-EERC-12-03 December 2010

FINAL REPORT

1. ARO PROPOSAL NUMBER: 57241-CH-DRP

2. PERIOD COVERED BY REPORT: October 1, 2009 – December 31, 2010

3. TITLE OF PROPOSAL: Jet Fuel Production from TAG and FAME

4. CONTRACT OR GRANT NUMBER: W911NF-09-1-0578

5. NAME OF INSTITUTION: Energy & Environmental Research Center, University of North Dakota

6. AUTHOR OF REPORT AND PRINCIPAL INVESTIGATOR:
Benjamin G. Oster
Research Engineer
Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018
Phone: (701) 777-5203
E-mail: boster@undeerc.org

EERC DISCLAIMER

JET FUEL PRODUCTION FROM TAG AND FAME

EXECUTIVE SUMMARY

The Energy & Environmental Research Center (EERC) and its partners have developed thermocatalytic technologies to produce a 100% renewable fuel from crop oil-derived triglyceride (TAG) feedstock that meets the critical military specification requirements of JP-8 as demonstrated by analysis conducted at the Air Force Research Laboratory (AFRL). The EERC process has demonstrated the ability to convert many types of crop oil TAG into hydrocarbon products. This project utilized the EERC process to convert algae oil TAG into JP-8 fuel components.

The fuel production process included hydrodeoxygenation of the algae feedstock to produce hydrocarbons, isomerization of the hydrocarbons, distillation of the isomerized hydrocarbons, and aromatics blending.

The EERC produced a 230-mL sample of finished JP-8 jet fuel and shipped it to AFRL for analysis. Initial EERC analysis indicated that the sample met JP-8 freeze point and flash point specifications.

TABLE OF CONTENTS

LIST OF FIGURES

JET FUEL PRODUCTION FROM TAG AND FAME

INTRODUCTION

Historically, the U.S. Army has relied on petroleum-based JP-8 fuel to power its vehicles and aircraft. In order to increase the surety of the Army's fuel supply, researchers are investigating JP-8 production pathways that convert alternative, domestic feedstocks into specification-compliant fuel. Algae is one promising feedstock because of its potential to produce very high yields of oil/acre/year and its ability to grow on nonfarmable land.

OBJECTIVE

The objective of this research was to demonstrate that algae-derived triglyceride oil can be processed into JP-8 fuel. Crude algae oil was shipped to the Energy & Environmental Research Center (EERC) by the Army Research Office. The crude algae oil was green and viscous, as shown in Figure 1.

EXPERIMENTAL

Due to the crude nature of the algae oil as-received, it could not be processed without further purification. The algae could not be pumped, even when heated, and contained solid plant matter. As such, the algae was shipped to POS Pilot Plant Corporation where it was purified via de-gumming and bleaching.

After receiving the purified algae oil from POS, the EERC began to process the algae oil into jet fuel range hydrocarbons. The crude algae oil was first pumped into a hydrodeoxygenation (HDO) reactor where the triglyceride oil was converted to hydrocarbons via three chemical reactions: 1) decarboxylation, 2) decarbonylation, and 3) reduction. Decarboxylation removes carbon and oxygen atoms from the parent triglyceride by the formation of carbon dioxide. Decarbonylation removes carbon and oxygen from the parent triglyceride by the formation of carbon monoxide. Reduction removes oxygen from the parent triglyceride by the formation of water. Reactions that remove carbon and oxygen result in hydrocarbons that contain one carbon less than the parent triglyceride. The reduction reaction, which only removes oxygen, results in hydrocarbons that contain an equal number of carbon atoms as the parent triglyceride. Because all three reactions occur simultaneously, the HDO product contains both odd and even numbered hydrocarbons.

The HDO reactor operated at elevated temperature and pressure and contained a fixed bed of commercial hydrotreating catalyst. A picture of the HDO reactor is shown in Figure 2. The HDO reactor products were hydrocarbons, carbon dioxide, carbon monoxide, and water. The hydrocarbon product was separated from the water layer for further processing. Specifically, a separation funnel was used to separate the hydrocarbon layer from the water layer. Typically, the HDO product contains 90mass% hydrocarbon and 10mass% water.

The hydrocarbon product from the HDO step contained predominantly normal paraffins. In order to improve cold-flow properties, the HDO product was pumped into an isomerization reactor. In this reactor, the normal hydrocarbons were branched to form isoparaffins, which have improved cold flow properties. Cracking reactions also occur in the isomerization reactor. These reactions convert longer chain hydrocarbons into shorter chain hydrocarbons. The isomerization reactor operated at elevated temperature and pressure and contained a fixed bed of isomerization catalyst. The product from the isomerization reactor contained a broad range of hydrocarbons and an increased concentration of isoparaffins.

The isoparaffin mixture was distilled in a batch distillation apparatus to separate jet range hydrocarbons from the product mixture. Finally, petroleum-derived aromatics were added to the jet range hydrocarbons in order to meet the JP-8 density specification. The blended JP-8 sample contained 140 g of algae-derived hydrocarbons and 42 g of petroleum aromatics.

EERC BO39297.CDR

Figure 1. Crude algae oil that was converted to JP-8 fuel.

Figure 2. Reactor system used to convert algae oil to JP-8.

RESULTS

A gas chromatography–mass spectrometry (GC–MS) instrument was used to analyze the algae-derived jet fuel, and as Figure 3 shows, the hydrocarbon composition was similar to that of JP-8 (JP-8 contains hydrocarbons ranging from C8 to C16). The blended JP-8 sample, shown in Figure 4, was analyzed at the EERC for freeze and flash points. The sample's freeze point was −63°C and its flash point was 44°C. JP-8 specifications dictate a freeze point below −47ºC and a flash point above 38°C. The finished fuel sample was shipped to the Air Force Research Laboratory (AFRL) for further analysis.

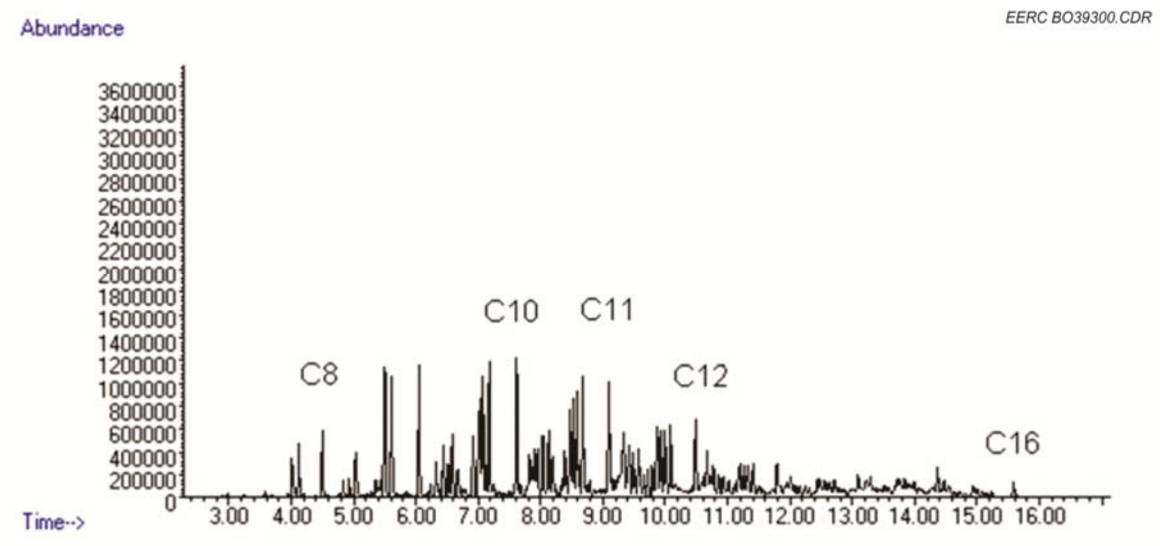

Figure 3. GC–MS chromatogram of algae-derived hydrocarbons.

Figure 4. Algae-derived JP-8 fuel that was shipped to AFRL for analysis.

CONCLUSIONS

Algae oil was successfully converted to jet-range hydrocarbons. The process consisted of three steps: 1) hydrodeoxygenation 2) isomerization and 3) distillation. Aromatics were added and the algae-derived JP-8 sample was shipped to AFRL for further analysis. In the future, algae oil could provide an alternative to petroleum for fueling military vehicles and aircraft.

This material is based upon work supported by or in part by the U. S. Army Research Laboratory and the U. S. Army Research Office under Contract/Grant No. W911NF-09-1-0578.